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INFORMATION PROCESSING IN A COMPLEX TASK UNDER SPEED STRESS

TECHNICAL DOCUMENTARY REPORT NO. ESD-TDR-64-391

MAY 1964

Alexander Z. Weisz
Linda S. McElroy

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FOREWORD

This report was prepared by Bolt Beranek and Newman Inc., Cambridge, Massachusetts under Air Force Contract AF 19(604)-8449 in support of Task 768201 of Project 7682, "Man Computer Information Processing." The work was administered by the Display Division, Decision Sciences Laboratory, Deputy for Engineering and Technology of the Electronic Systems Division. Dr. John Coules served as contract monitor and contributed to the planning of the work.

Professor Nancy S. Anderson of the University of Maryland was generous in providing advice and constructive criticism during the course of a summer spent at this laboratory.

John B. Brown, Creighton M. Gogos, and William E. Fletcher designed the data insertion techniques utilized in the response panel constructed for the experiment. Donna L. Darley and Sheldon Boilen made important contributions in computer programming.

This is the final report and concludes work on Contract AF 19(604)-8449. This report has also been issued as Bolt Beranek and Newman Inc. Report No. 1129.

ESD-TDR-64-391

INFORMATION PROCESSING IN A COMPLEX TASK UNDER SPEED STRESS

ABSTRACT

Differential effects of speed stress were sought in a complex task including five information processing activities differing in a) spatial and temporal uncertainty of events requiring response, b) location in display channels varying in frequency of occurrence of response events, c) short-term memory requirements, and d) perceptual requirements in event recognition. Highly practiced Ss were found to have evolved a priority strategy based primarily on frequency of response events in different display locations. High frequency tasks not requiring search were relatively impervious to stress effects. Lower frequency events occurring in low priority display locations gave rise to poorer performance at all levels of stress. Significant performance decrement under stress occurred first in the most complex low probability task, which required search and short-term memory. The results were interpreted as being similar to findings in studies of vigilance behavior and statistical decision theory.

PUBLICATION REVIEW AND APPROVAL

This Technical Documentary Report has been reviewed and is approved.

DONALD W. CONNOLLY
Chief, Display Division
Decision Sciences Laboratory

ROY MORGAN, Colonel, USAF
Director
Decision Sciences Laboratory

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SECTION 1

INTRODUCTION

Many current man-machine systems include human operator tasks which require the individual to deal with a number of information sources simultaneously. Under operational conditions such tasks can impose severe stress on the operator in terms of the rate and variety of information-processing activities required. Studies carried out within a variety of contexts have demonstrated that performance typically improves as task stress or rate of information input increases for a period of time. Information-processing performance levels off with further increase in the demands of the task, followed typically by a drastic reduction in adequacy of performance under more serious overload conditions. This study was undertaken to attempt to find aspects of performance in complex tasks highly sensitive to task-induced stress which show greater decrements in performance at intermediate levels and are thus predictive of more general disruption of performance at higher levels of task stress.

Several general experimental approaches have been developed in which major variables concerned with task stress have been investigated. One such approach, initiated by British investigators (Conrad, 1951, 1955; Mackworth and Mackworth, 1956, 1957) has been concerned with the rates at which displayed information changes and the number of separate, independent streams of signals or display channels that require simultaneous consideration. These studies have demonstrated that speed and load act as essentially independent variables contributing to task stress. The findings of Conrad and Mackworth indicate that in multi-channel displays performance decrement is in large part due to

the momentary bunching or overlap of signals which inevitably occurs if information is arriving at different rates in the various channels.

Investigation of speed and load variables has been extended in this country with different tasks and the use of information measures of task complexity (Wagner, Fitts, and Noble, 1954; Sidorsky, 1954; Jeantheau, 1959). These studies indicate that the difficulty of a dynamic task is not only a function of speed and load, but also of the information content of the display. A study by Jeantheau (1959) has demonstrated that the use of information measures in specification of task characteristics adds little to our ability to explain performance under stress. Jeantheau found that a more pertinent and fruitful approach in analyzing such tasks is in terms of the actual operations S is required to perform in responding to the situation.

A major shortcoming of this body of research is that, despite the use of multi-channel tasks, the constituent activities employed have been homogeneous. We have no data concerning the effects of speed and load stress on complex tasks in which display channels or subtasks vary in type or complexity of information processing required. Further, these studies have not included tasks which require storage and integration of information over time; discrete response activities have been employed in order to simplify the analysis of performance.

The research reported here was undertaken to extend the study of the effects of task-induced stress to complex tasks more representative of human operator activities in man-

machine systems. In devising an experimental task, the following questions were considered. If activities varying in type and complexity of information-processing are included in a complex task, are there differential effects on performance in the various subtasks under increasing levels of speed stress? Can such differential effects by related to task characteristics such as information-storage requirements, frequency of occurrence, search requirements, number of items or cues which must be discriminated and integrated, and location in display channels which differ in the frequency of occurrence of significant events?

A detailed investigation of these questions would obviously call for a large-scale program of research. The strategy employed, therefore, was that of carrying out an exploratory study in which variables were confounded in an attempt to uncover promising general lines of approach which might be subjected to more precise evaluation in further tests. The study was exploratory in a second area, since a digital computer was programmed to display information, pace the task, record responses, and analyze data.

SECTION 2

METHOD

Experimental tasks. The experimental situation included a primary monitoring or decision-making task corresponding, in terms of uncertainty and information storage, to the complexity of information-processing requirements in operational situations. Additional secondary tasks were included to represent discrete activities simultaneous with the ongoing primary task. These secondary tasks were chosen to vary in spatial and temporal uncertainty as well as in difficulty and type of information-processing required. A set of five tasks, tested in preliminary experiments was utilized to constitute the complex task for this study.

Identifying the variations of four geometric forms appearing in the quadrants of the computer-generated cathode ray tube display was the basic activity involved in carrying out the various experimental tasks. The geometric forms appearing in these quadrants, beginning at the upper right and proceeding clockwise, were a rectangle, trapezoid, triangle, and parallelogram. On each presentation or frame of the display a form appeared in one of seven variations differing in base-altitude ratio. The base-altitude ratio variations formed an ordered series centered on a "standard" form in which base and altitude dimensions were 1.08 inches. The seven variations of the forms are shown in Figure 1. In each form series, variation steps to the right and left of the middle form differed by .90 inches in base or altitude, a value chosen to maximize discriminability within the space limitations of the display area. One task also required Ss to discriminate the two spacing values between points painted on the CRT to construct the forms. The point spacing values employed are illustrated in Figure 1.

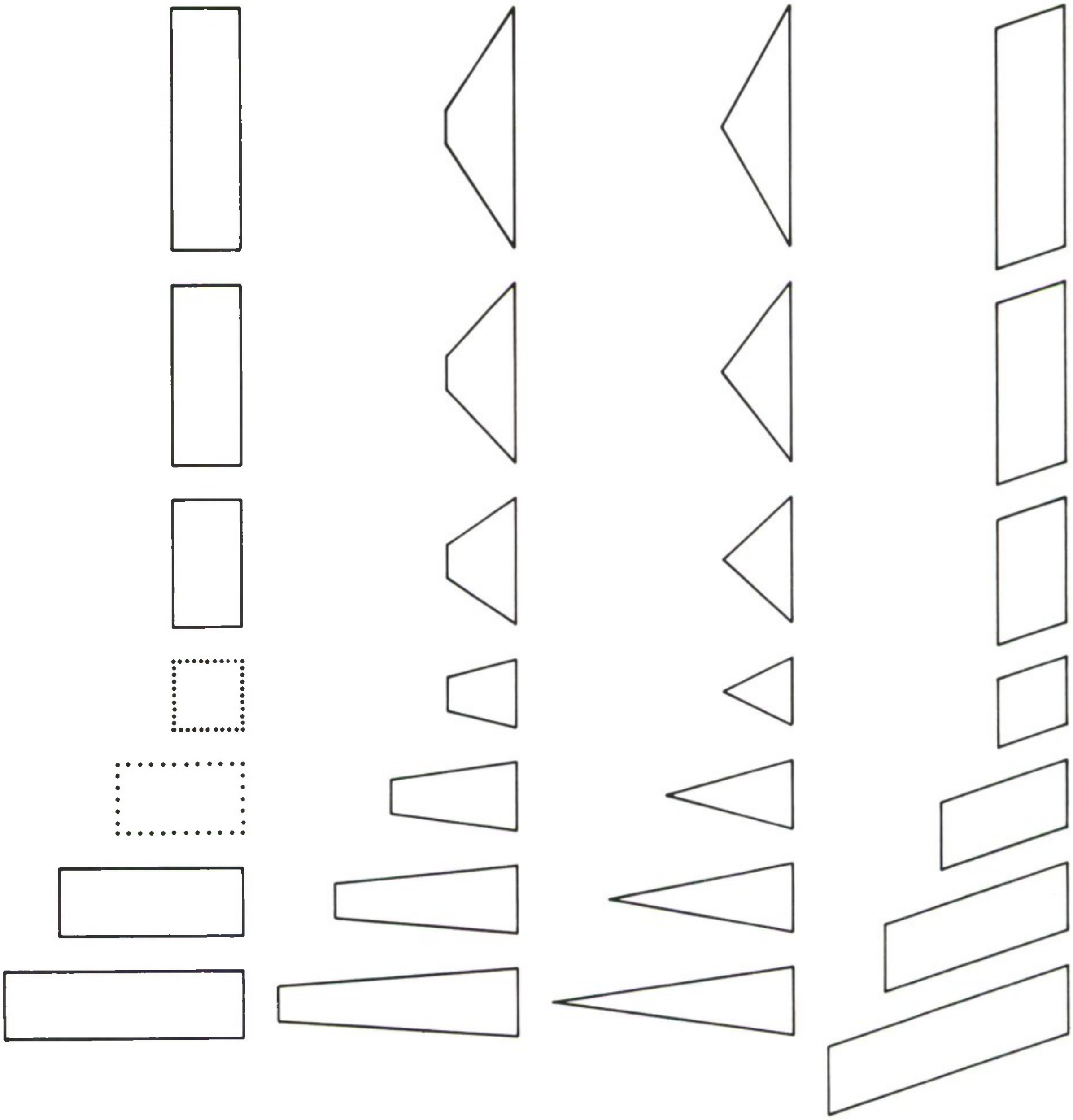


FIG.1 THE FOUR ORDERED SERIES OF FORM VARIATIONS

On each display frame S searched the display for the occurrence of five different classes of events. The MEAN task required S to estimate the population mean for the rectangles appearing in the upper right quadrant, keeping track of the form values on successive frames in order to discriminate among five possible distributions centered on the five middle form variations. During each experimental trial the mean shifted once from an initial value to a second mean value. S was instructed to insert a mean estimation response on each frame, except when the mean was judged to be centered on the middle or "standard" form value; at these times S identified the form value appearing on each frame.

The rectangle form values were selected for display by random sampling from a gaussian-normal distribution. Since there were only seven form variations employed, a skewed distribution resulted when the mean was shifted one or two positions from the middle or standard form value. An important clue to S of the direction and magnitude of a mean shift from the middle value was the relative frequency of extreme form values in the series.

The FORM task required S to identify the form value for the trapezoid appearing at the lower right on each frame. It thus served to balance the frequency of occurrence of response events between the two right-hand display quadrants.

The mean estimation and form identification tasks were chosen to vary widely in level of difficulty, to utilize information presented in a single quadrant location, and to call for a response on each frame. In contrast, the remaining

three tasks were less predictable, in the sense that an event calling for response did not occur in every frame. These events were variable in location and required searching more than one display quadrant, thus permitting a comparison of performance between occurrences on the high-priority right side of the display and those involving other quadrants.

The PAIR task required detecting pairs and triples -- forms of identical base-altitude dimensions -- appearing in a single frame. Four linkages for pairs were possible, with non-adjacent diagonal linkages excluded. Triples could also occur in four locations.

The RUN task required S to remember the location of pairs and triples and check for the appearance of another pair or triple in the same quadrant locations on the next frame. The second pair or triple was not necessarily of the same base-altitude value as the preceeding combination; the common relationship required was similar location on two successive frames. A correct response therefore required identification of a pair or triple on the preceding frame, short term memory of its location, and identification of a second pair or triple.

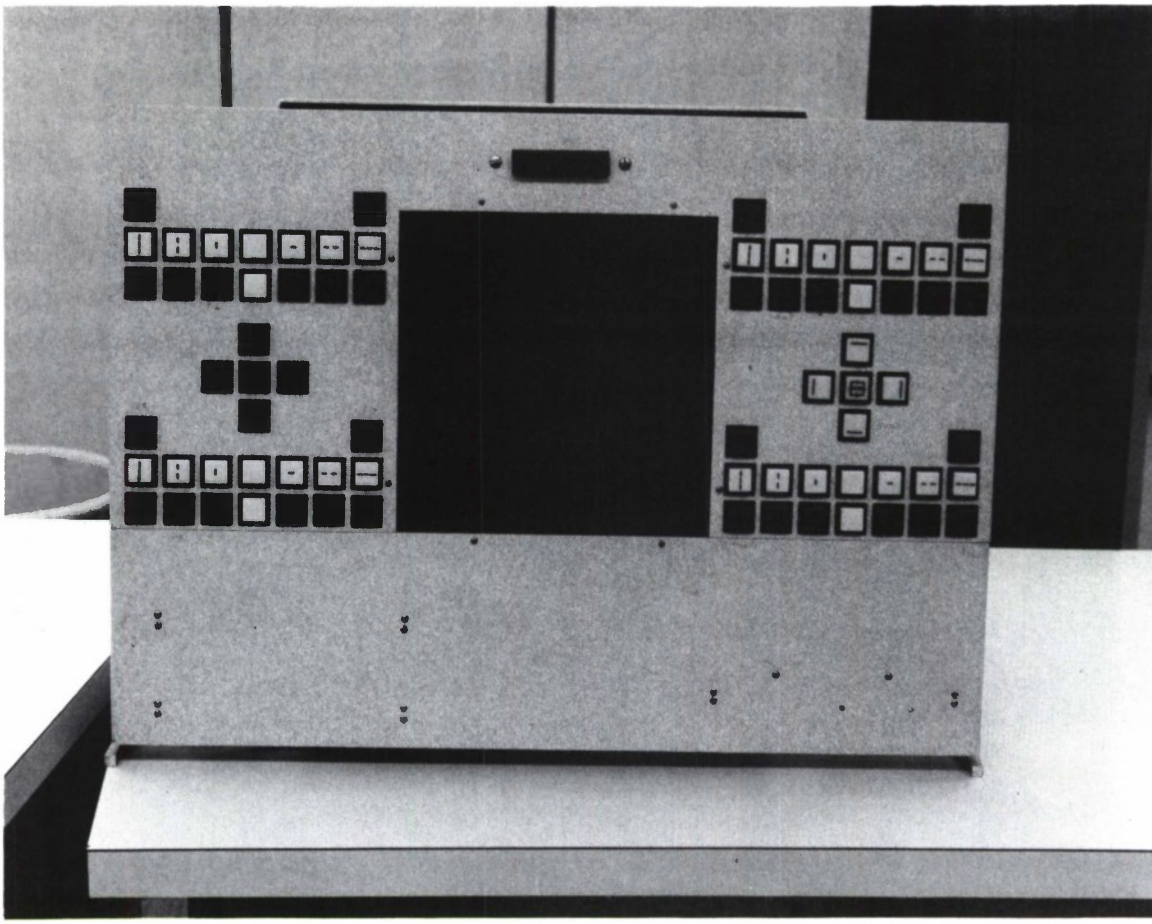
In contrast to the PAIR and RUN tasks, which encompassed all four quadrants and entailed correlating information from several quadrant locations, the LINE task presented the relevant information within a single quadrant location. S only responded to LINE events in the two lower quadrants. In this case S watched for a close point spacing in form outline occurring with a trapezoid or triangle of extreme altitude or base dimension. He thus had a relatively easy discrimination task

calling for identification of the two extreme form variations of the seven possible alternatives, with the additional information, dot spacing, appearing as a second attribute of the form.

Apparatus. The visual displays were constructed and presented, and responses recorded and scored by a digital computer.[1] The geometric forms were presented within a 10-inch square area of the cathode ray tube display of the computer.

A response panel on which were mounted 75 momentary-contact pushbutton switches was utilized for response insertion. The response panel entailed development of a means of response insertion to the computer which could be utilized with greater ease and speed than the standard typewriter and light pen equipments available. The pushbutton switches were connected with resistors to provide distinctive voltages to an analog-to-digital converter. A second circuit connected to the response switches provided a signal to the computer to read the voltage value at the analog-to-digital converter when a pushbutton was pressed. The activated switch was then identified by the computer by comparing that voltage value with a pre-stored calibration table. Some persistent difficulties with this portion of the equipment and programs earlier necessitated extensive trouble-shooting and writing of additional computer check routines. Despite this effort, a small percentage of responses were not identified by the computer in this experiment, necessitating deletion of approximately 1% of the responses as unscoreable. In every case it was possible to identify the particular stimulus

1. Digital Equipment Corporation PDP-1B computer.



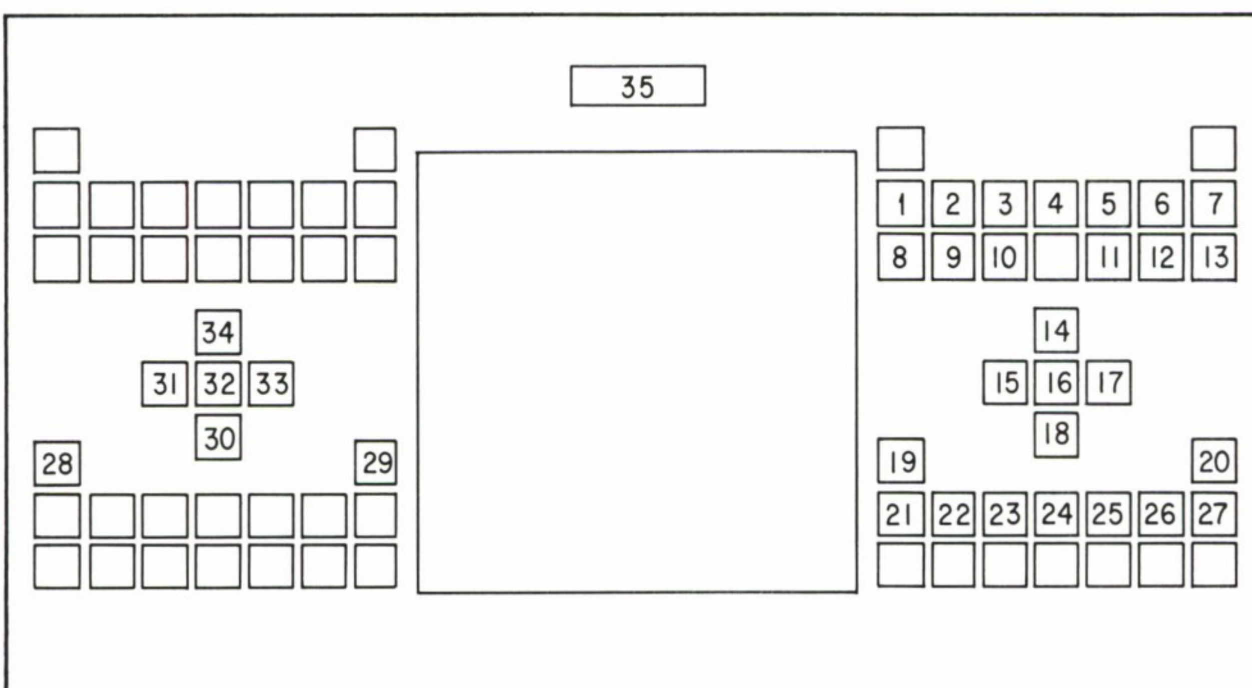


FIG. 2 (above) RESPONSE PANEL IN POSITION IN FRONT OF COMPUTER CRT DISPLAY

(below) PUSH BUTTON SWITCHES USED FOR RESPONSE INSERTION IDENTIFIED BY NUMBER

to which the unscoreable response had been made, so that it could be excluded from S's score in that task category. The deleted responses were well distributed among the five tasks.

The response panel was constructed to allow for a greater variety of tasks than were included in this experiment. Of the 75 pushbutton switches, 33 were utilized for response insertion. The response buttons for each task, of .75 inch square size, were color and position coded for ease of identification.[2] Individual pushbuttons within each response group also bore an inscribed legend to assist in discriminating alternatives. The response panel in position before the CRT display is shown in Figure 2. The pushbutton switches utilized for this experiment, identified by number in Figure 2, were employed as follows:

1-7 (green) - employed to identify the form value appearing in each frame when S judged the mean of the distribution of rectangle form values to be centered on the middle or standard form value.

8-13 (white) - employed to insert an estimate of the current value of the mean when S judged the mean to have shifted away from the center form value.

14-18 (yellow) - employed to identify the occurrence of pairs and triples in the PAIR task. The four outer switches of the cross corresponded to the four possible pair locations. Switch 16 at the center of the cross was utilized to signal triples.

---

2. Pendar type 25-1018 momentary-contact pushbutton switches.

19-20 (red) - employed for LINE task occurrences in the lower right quadrant.

21-27 (green) - employed for the FORM task.

28-29 (red) - employed for LINE task occurrences in the lower left quadrant.

30-34 (blue) - employed for the RUN task.

35 (red) - employed for two functions; as an error light which was activated to signal S that he had not depressed a switch far enough to give rise to a voltage; and as a means for S to delete a response if he pressed the wrong button.

A blue plastic filter placed in front of the CRT permitted S to see the blue flash of the P-7 phosphor but masked the yellow-green fluorescent trace.

Display generation characteristics. Two aspects of the computer programs utilized to generate displays are of importance in understanding S's task. These are concerned with the techniques utilized to determine the number of display frames in a trial and the scheduling of occurrences of tasks within the series of display frames constituting a trial.

A trial consisted of two series of frames, each series corresponding to a different value of the mean for the mean estimation task. The number of frames in a series varied

between 10 and 20 on the basis of a random decision made at the beginning of each series. Since there were two such series in a trial, trial length could vary between 20 and 40 frames.

The occurrence and location of similar base-altitude forms for pairs and triples were determined by a random selection procedure intended to give rise to PAIR occurrences on half of the frames, with a RUN scheduled for the following frame in one-third of these cases. The computer routine employed for approximating a series of random numbers was later found to have caused some variation from the intended values. LINE occurrences were scheduled by having a narrow dot spacing occur randomly for one-fifth of the forms presented in all quadrants. The presence of an extreme form value in the lower quadrants was a semi-random event influenced by form value selections in the upper right quadrant, as well as PAIR and RUN decisions.

The percentage of trials on which response-evoking events appeared for the various tasks are listed below:

MEAN (upper right quadrant)	100%
FORM (lower right quadrant)	100%
PAIR (all quadrants)	44%
RUN (all quadrants)	14%
LINE (lower quadrants)	12%

Since the tasks varied in frequency of occurrence, the number of button-push responses required varied from frame to frame. Two responses were called for on 27% of the frames, three responses on 64%, and four responses on 7%.

Procedure. Six male Ss were tested. They had served in a preliminary experiment employing an earlier version of the experimental task. In the preliminary study a trial included four mean estimation series, the first and third of which were zero mean shift cases. Initial trials were run at a frame time of 13 seconds duration. Frame times were successively reduced to 10, 8, 6 and 4 sec. as S was able to achieve an error rate of 20 percent or less. At the end of each trial the data were analyzed and S was provided detailed knowledge of results in the form of a computer-generated listing of percent error and frequency of occurrence for each task. Ss were given approximately three hours of practice under these conditions.

In the experiment reported here, each S was tested under three frame-time values chosen to range between a leisurely pace and extremely fast work. For four of the six subjects, frame times were 10, 7, and 4 sec. The remaining two Ss had demonstrated less ability in the preliminary experiment to deal with the task at higher levels of speed stress. These Ss were tested at frame times of 10, 7, and 5 seconds.

At the end of each frame, the display was interrupted for approximately 1 second while response data were punched off on paper tape. Late responses entered during this period were not recorded for analysis. S was instructed to attempt to insert responses on each frame during the display period.

An initial practice period was provided in which Ss received two trials at each of the three frame-time values. On subsequent days Ss received six trials at each of the three frame times. Nine trials were given in each of two experimental

sessions. Within each session, S had three trials, one at each frame time, in immediate succession, followed by a rest interval during which a second S was tested. Three such groups of trials constituted a session of approximately two hours duration.

The six trials at each frame time employed six different mean estimation sequences in which the three levels of deviation of the mean from the central value (0, $\pm$ 1, $\pm$ 2) were equally represented in the first and second mean estimation series. The experimental design was balanced for order of mean extimation sequences and order of frame times within groups of three trials.

SECTION 3

RESULTS

Percent error scores. An initial data analysis utilized percent error scores computed for each subtask on the six trials at each frame time. Since the feedback provided Ss in training during the preliminary experiment focussed attention on the contribution of task scores to overall error rate on the task, the percent contribution of errors on each task to total errors at each level of speed stress was also determined. Mean values are presented in Table 1, together with mean error rates on all subtasks combined and data on frequency of occurrences in the various tasks. The mean percent error values are also shown in Figure 3.

At the 10-second frame time, the overall error value of 18.4 percent was largely attributable to the mean estimation task, which was responsible for 73.5 percent of all errors recorded. Error rates on all other tasks were considerably lower in the absence of speed stress. The intermediate stress level provided by the 7 second frame time resulted in small increases in error percentages for all tasks except the RUN category, in which a larger increase in error occurred. The rank order of difficulty of the tasks remained unchanged from that found at the 10-second frame time, with little change in the overall error rate or relative contributions of tasks to total error.

Very marked changes in the pattern of errors resulted at the highest level of speed stress, together with a larger increase in total error rate. The MEAN task, despite its

TABLE 1

Percent Error and Percent of Total Errors
At Each Frame Time for Experimental Tasks

	MEAN	FORM	PAIR	RUN	LINE	TASKS COMBINED
No. of Occurrences	3253	3220	1406	452	379	8710
% of Total Occurrences	37	37	16	5	4	100
			Percent Error			
Frame Time (sec.)						
10	36.8	2.5	16.6	20.6	7.4	18.4
7	41.2	4.0	20.1	34.8	10.2	22.4
4-5	37.9	16.6	47.0	50.0	40.2	32.2
			Percent of Total Errors			
Frame Time (sec.)						
10	73.5	5.0	14.7	5.9	2.0	100
7	69.1	6.6	14.4	8.0	1.8	100
4-5	44.1	19.2	24.1	7.8	4.8	100

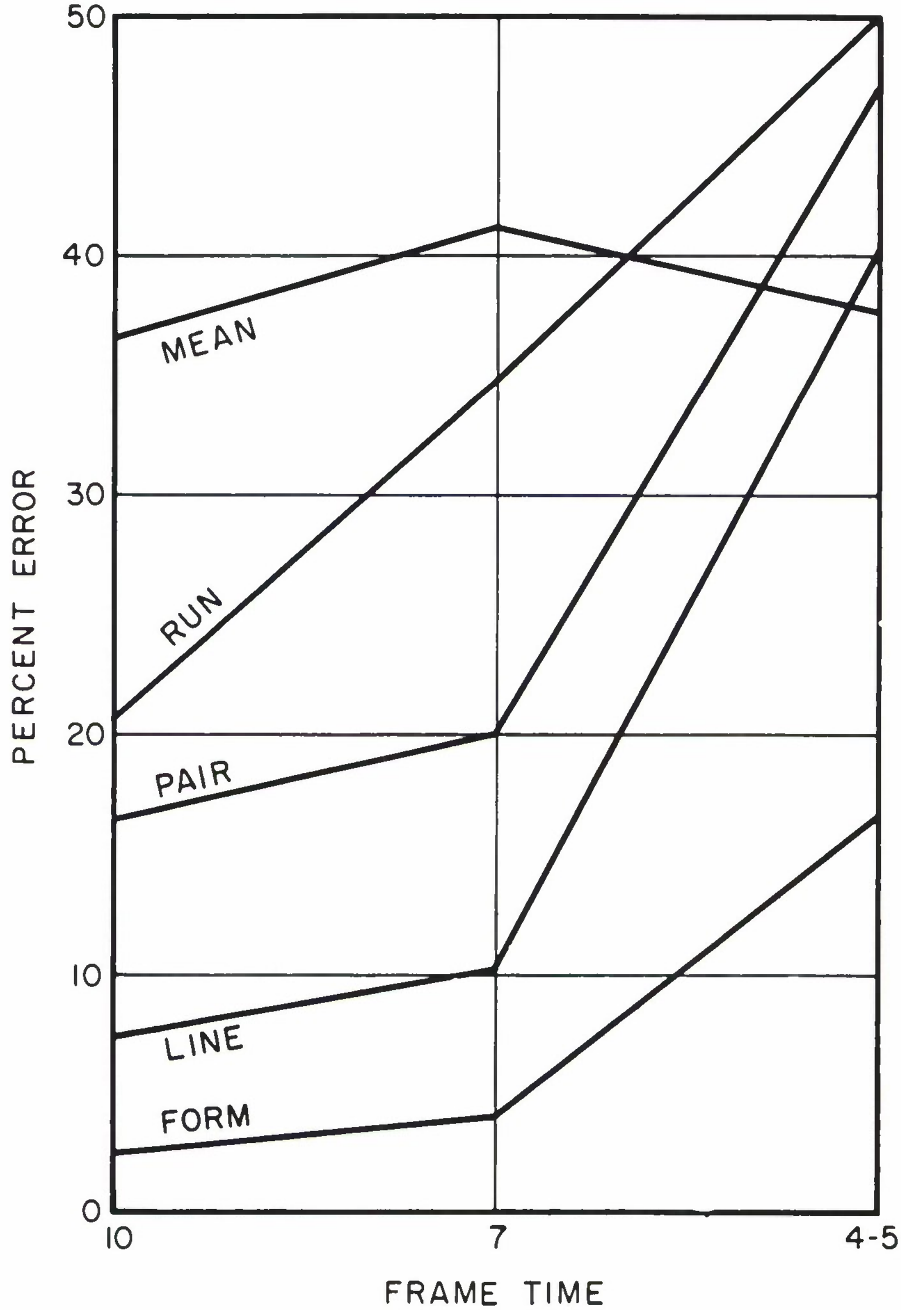


FIG. 3 PERCENT ERROR IN TASKS AS A FUNCTION OF DECREASED FRAME TIME

difficulty, was unaffected by increased stress, with a consequent reduction in its contribution to total error. The second task not involving temporal or spatial uncertainty, FORM, showed an increase in error substantially smaller than those found for the remaining activities.

An analysis of variance was performed on the percent error scores for the various tasks. The results of this analysis are summarized in Table 2, where it may be seen that the main effects of Tasks and Frame Times are highly significant, as well as their interaction.

It appears from Figure 3 that performance on the MEAN and RUN subtasks contributed strongly to the significance of the Tasks x Frame Times interaction. Further analysis indicates this to have been the case.

Evaluation of the differences in performance within each task at the 10-and 7-second frame rates, utilizing the *t* test for paired comparisons, demonstrated that the increase in error scores for RUN was significant at the .01 level, while none of comparisons for the other tasks proved significant. A second set of tests comparing performance at the 7 and 4-5 second frame rates gave rise to significant values for the FORM, PAIR, and LINE tasks at the .02, .01, and .01 levels; neither the MEAN nor RUN differences proved to be significant. Thus the RUN task showed a performance decrement at a lower level of speed stress than any of the other activities included, while the mean estimation task showed no decrement under stress.

TABLE 2

Analysis of Variance of
Percent Error Scores

Source	df	MS	F	p
Tasks (T)	4	2889.62	11.62	$<.001$
Frame Times (F)	2	3670.05	26.88	$<.001$
Subjects (S)	5	174.47		
T x F	8	379.95	7.84	$<.001$
T x S*	20	248.75	5.14	$<.001$
F x S**	10	136.52	2.82	$<.01$
T x F x S***	40	48.44		

* Error Term for T

** Error Term for F

*** Error Term for T x F, T x S, F x S

Response errors and errors of omission. The previous analyses were based on error scores which did not distinguish between errors due to insertion of an incorrect response and those resulting from failure to respond. There were large differences in the proportions of these two classes of error for the various tasks, as shown in Table 3. Omission scores are also presented graphically in Figure 4. The two activities in which a response was called for on each frame, MEAN and FORM, gave rise to the lowest omission error scores at all frame-time values. For all of the tasks which did not require memory of events in preceding frames of the display, the FORM, PAIR, and LINE activities, performance decrements under speed stress were almost entirely attributable to errors of omission. In fact, the only case in which response errors appear to have contributed moderately to performance decrement under stress is found in the RUN task.

Inspection of the omission scores revealed a strong heterogeneity of variance among experimental conditions, precluding the use of parametric techniques in analysis of these data. A nonparametric test, the Friedman two-way analysis of variance (Siegel, 1956), was employed to test differences between tasks. Separate analyses were carried out for the three frame-time conditions. The values of X_r^2 for the 10, 7, and 4-5 second frame times were significant at the .05, .05, and .01 levels respectively, indicating significant differences in omission errors among tasks at each stress level.

X_r^2 values were also computed for each subtask in testing the significance of differences in omission scores at the three frame times. These differences were significant ($p < .02$) for all of the subtasks with the exception of MEAN. Further analysis,

TABLE 3

Percent Error Due to Response Errors and Omissions

Frame Time	MEAN Response Errors	Omissions	Total
10	36.2	0.6	36.8
7	39.9	1.3	41.2
4-5	36.4	1.6	37.9

Frame Time	FORM Response Errors	Omissions	Total
10	1.6	0.9	2.5
7	2.0	2.0	4.0
4-5	3.2	13.3	16.6

Frame Time	PAIR Response Errors	Omissions	Total
10	10.6	6.0	16.6
7	11.2	8.9	20.1
4-5	13.8	33.1	47.0

Frame Time	RUN Response Errors	Omissions	Total
10	18.7	1.9	20.6
7	28.8	6.0	34.8
4-5	28.5	21.5	50.0

Frame Time	LINE Response Errors	Omissions	Total
10	4.0	3.4	7.4
7	3.4	6.8	10.2
4-5	1.8	38.4	40.2

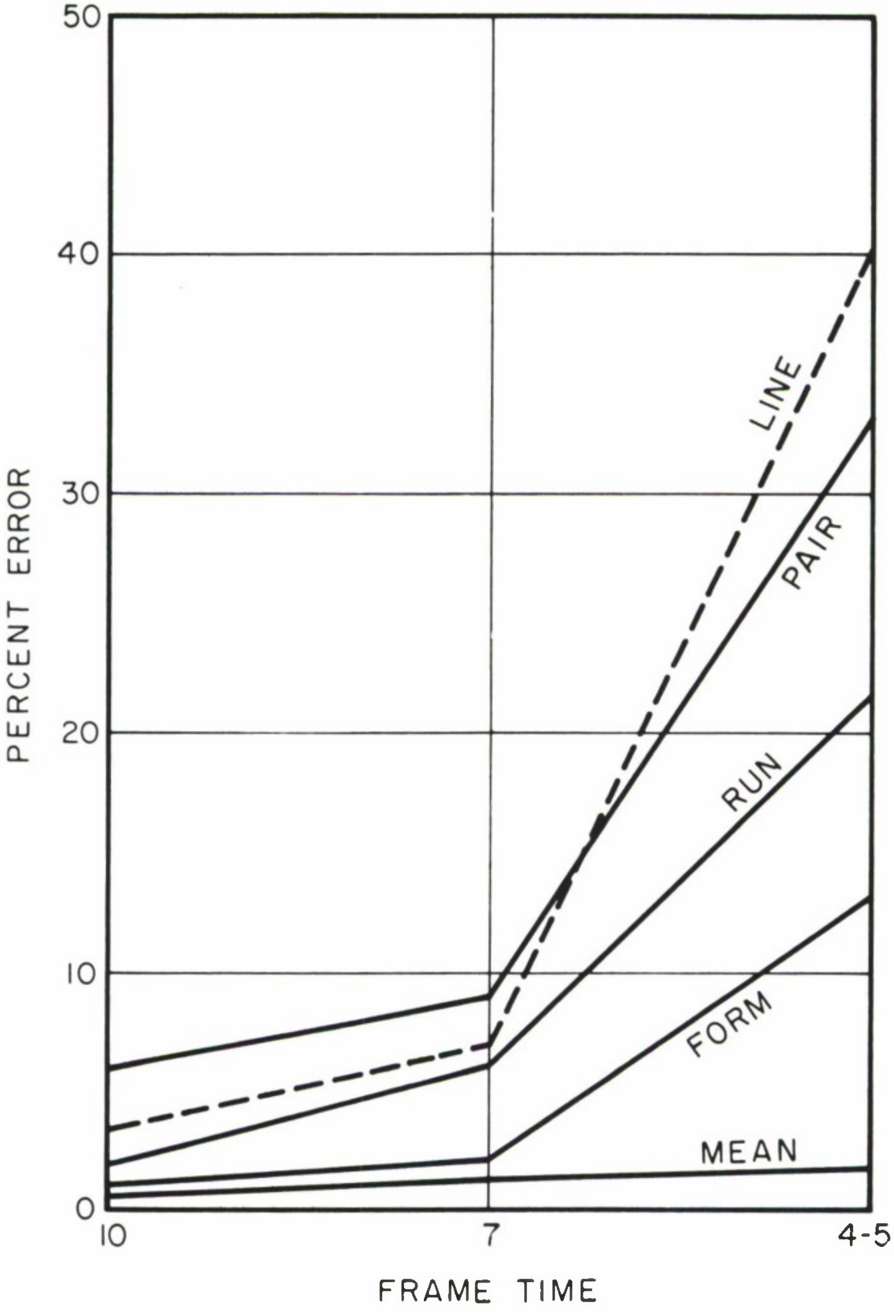


FIG. 4 PERCENT OMISSION ERROR IN TASKS AS A FUNCTION OF DECREASED FRAME TIME

utilizing the Wilcoxon signed-ranks test (Siegel, 1956) established that, for the FORM, PAIR, RUN, and LINE activities, omission error percentages differed significantly between the 7 and 4-5 second frame times ($p = .05$); none of the comparisons between the 10 and 7 second conditions proved to be significant.

Effects of location in the display. Further analyses were carried out to assess the effect of display location upon detection of events in those tasks involving spatial and temporal uncertainty. The LINE task provided a comparison between events occurring in the lower right quadrant of the display, to which S's attention was directed on each frame by the requirement to insert a FORM response, and the lower left quadrant, in which the probability of occurrence of an event requiring response was smaller.

The PAIR and RUN tasks permitted a similar comparison between pairs occurring on the left and right sides of the display. These tasks also included mixed pairs and triples spanning the two sides of the display. Although the triples required correlating information from three locations rather than two, an initial comparison of performance on mixed pairs and triples demonstrated that differences were not statistically significant at any of the frame-time values in either the PAIR or RUN tasks. Data for these two categories of events were therefore pooled in further analyses.

Percent error scores based on pooled response errors and errors of omission were employed, since the small number of events at each display location for the RUN and LINE tasks

did not permit further fractionation of the data. These results are summarized in Table 4 and are presented graphically

TABLE 4

Percent Error According to Display Location

	Frame Time	Display Location Left	Mixed	Right
LINE	10	20.0		3.2
	7	17.5*		4.2
	4-5	63.7*		12.0
PAIR	10	22.0*	10.8	5.7
	7	26.0*	15.7	9.0
	4-5	54.3*	48.2	33.3
RUN	10	27.7	15.5	26.0
	7	41.3	23.0*	44.5
	4-5	51.2	42.2*	61.8

* Difference from performance at Right display location significant at .05 level.

in Figure 5. Analysis of these data required the use of non-parametric methods, since there were marked departures from a normal distribution of scores at the right for the LINE and RUN tasks, where half or more of Ss made no errors at the 10 and 7 sec. frame times.

It is apparent in Figure 5 that for the LINE task there was a marked difference in the effect of speed stress on the left and right sides of the display. The low error rate observed at the right for the 10 sec. frame time was maintained under increased stress; the slight trend toward increased error at shorter frame times is not significant ($.570 > p > .430$)

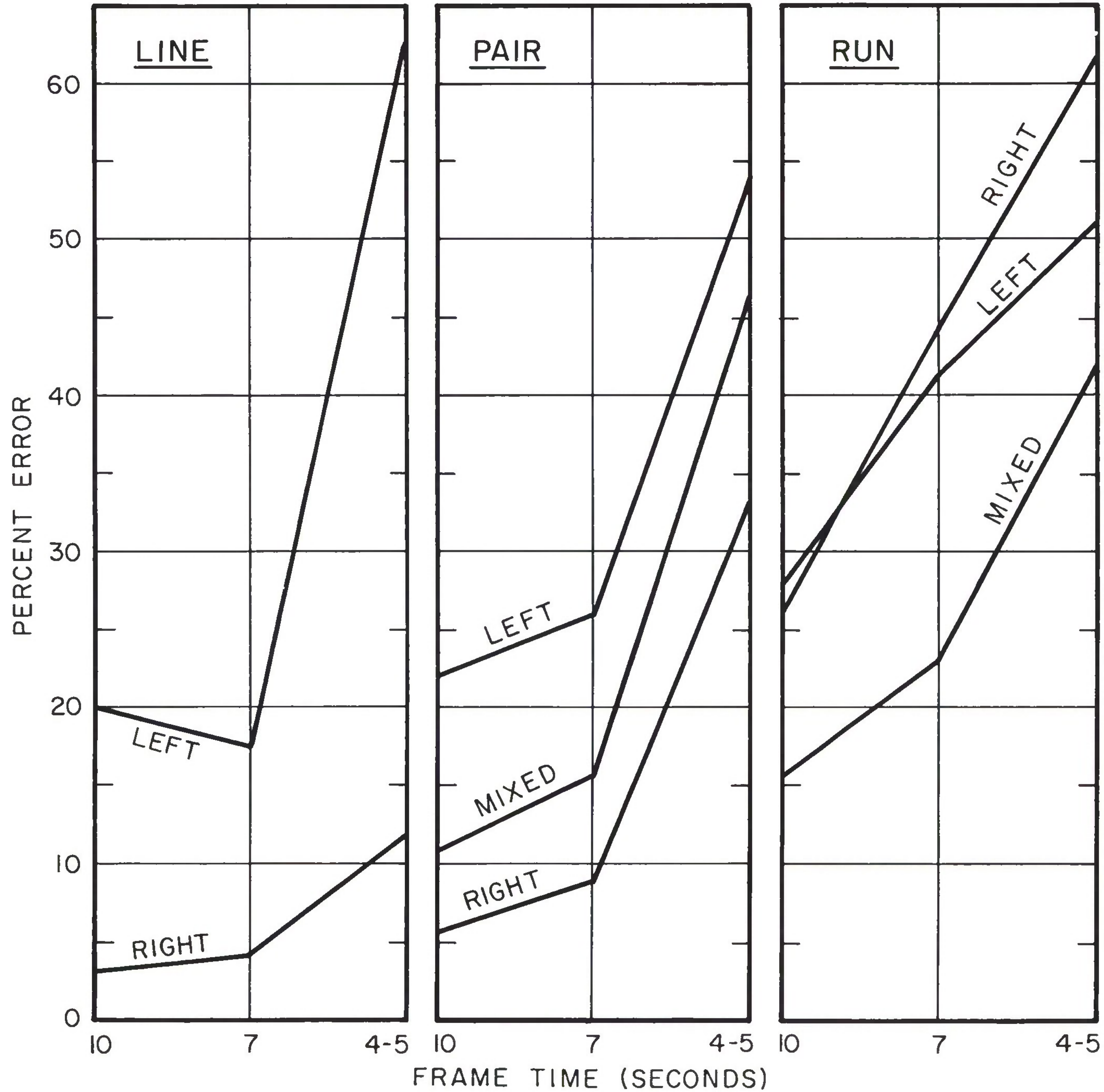


FIG. 5 TASK PERFORMANCE ACCORDING TO DISPLAY LOCATION

when tested by means of the Friedman analysis of variance. In contrast, the trend for scores on the left is highly significant ($.0017 > p > .00013$). The interaction between display location and frame time, evaluated by means of the Wilcoxon extension of the Friedman test (Wilcoxon, 1949), is also highly significant ($.0055 > p > .0017$). These results indicate that responding to LINE events on the high-priority side of the display was not affected by stress, while errors on the left showed a significant increase.

The significance of differences between LINE scores at the left and right at each frame-time value, determined by means of the Wilcoxon matched-pairs signed-ranks test, are given in Table 4. These results indicate that the higher error rate found at the left is not significantly different at the 10 sec. frame time, but does achieve significance under increased speed stress.

For the PAIR task, increased stress apparently did not have a marked differential effect upon performance at the various display locations. The trend toward increased error at shorter frame times is highly significant for both left and right locations ($.005 > p > .0017$), while the test of the interaction between these display locations and frame time does not approach significance ($p = .740$). The results of the tests of the significance of differences between PAIR error scores summarized in Table 4 indicate a gradient of difficulty from right to left at all levels of stress in that performance on Mixed events spanning the left and right sides is not significantly poorer than on the right, while the left-right differences are significant at all frame times for this task.

A similar gradient of difficulty is not found in the results for the RUN task. The lowest error rates were observed for the Mixed events at all frame times, with percent error significantly higher for occurrences on the right 7 and 4-5 sec. Differences between right and left scores were smaller and not significant at any of the three frame-time values. The display location - frame time interaction for the right and left scores is not significant ($p = .740$).

It is apparent from these results that the effect of display location on performance in this task, which required identification and short-term memory of events, was markedly different from that found for PAIR and LINE, in which only identification was required. In attempting to find the basis for this difference, it was noted that performance at the left and mixed display locations for the PAIR and RUN tasks was markedly similar; differences in error rates between these tasks at these locations was small at all frame times. In contrast, large differences at the right location between the two tasks are evident in Figure 5 and Table 4.

The significance of these differences was tested with Wilcoxon's technique for comparison of two treatments made under several different conditions (Wilcoxon, 1949, p.6), as well as with the more widely known, but less appropriate, Wilcoxon signed-ranks test (Siegel, 1956). For both tests, the findings are the same. For both the left and mixed locations, performance on the Pair and Run tasks do not differ significantly ($p > .05$) over the three frame times. At the right, differences are highly significant ($p < .01$) over all frame times. These findings indicate that while position in

high-priority display locations is of assistance in detecting lower probability events, this advantage does not extend to a more complex activity which entails short-term memory.

The results of another set of comparisons reinforces this conclusion. Performance scores at the right for LINE, PAIR, and RUN were compared with those for FORM task occurrences in the lower right quadrant (Wilcoxon signed-pairs test). The LINE and PAIR scores are not significantly different from FORM performance at any of the three frame times, while the RUN-FORM comparison is significant ($p = .05$) at both 7 and 4-5 sec.

Additional analyses of MEAN task performance. Although the MEAN task proved to be least affected by speed stress of all of the activities included in the study, it might be argued that this was due to the fact that estimation of the mean represented so difficult a task that performance was essentially at a chance level at all levels of stress. There is evidence to indicate that this was not the case. It was found that the three values of the mean which were included, 0, $\pm$ 1, and $\pm$ 2 deviation steps from the middle form value, differed in mean percent error. Table 5 shows that the 0 and $\pm$ 2 values were less difficult to discriminate than the intermediate $\pm$ 1 step. This difference was maintained at all levels of speed stress.

TABLE 5

Percent Error in Mean Estimation According to Mean Value

Frame Time	Value of Mean		
	0	±1	±2
10	24.5	56.5	25.1
7	30.8	57.6	31.4
4-5	29.1	54.3	24.4

In view of these apparent differences in the difficulty of the mean estimation task according to the value of the mean, several analyses were carried out to determine whether performance on the other tasks was influenced by the difficulty of the mean values included in a trial. No evidence of such an effect was found.

Another aspect of performance on the Mean task was also investigated. A measure of latency, developed for an earlier version of the task, provided a basis for estimating the number of frames required for S to first detect that the mean had shifted from its initial value in a trial. A slight trend toward increased latency under stress was found, the mean number of frames rising from 2.5 at 10 sec. to 3.2 at 7 sec., and to 3.6 at 4-5 sec. None of the differences proved to be significant.

SECTION 4

DISCUSSION

The experimental results indicate that Ss utilized a priority strategy in dealing with the various tasks which was based on the relative frequency of response required for the tasks and display locations. This strategy, developed during the extended practice which they received prior to the experimental trials, was evident in the order in which responses were entered. The general procedure evolved by all Ss was to first deal with the MEAN task at the upper right. The only exceptions which were observed occurred for RUN responses, where S occasionally placed his hand in position at the RUN response button at the end of a frame in which a PAIR response had been inserted. This was done to serve as a memory aid, in preparation for a possible RUN occurrence on the following frame.

There is some indication that priority was not solely determined by frequency of occurrence, but also by the relative importance of attending to a task category in minimizing error. Ss were aware that the MEAN task contributed most heavily to error scores. Moreover, the loss of information from a single frame could have more serious consequences in mean estimation than in the discrete stimulus-response tasks. Ss apparently made certain that they attended to MEAN within the time available. The FORM task, although equally frequent in occurrence, was attended to after the MEAN response had been entered. As a consequence, omission errors at the shortest frame time were higher for FORM than MEAN. Although the arrangement of push-buttons on the response panel may have contributed to establishing the priority strategies employed, in this experiment the effects

of speed stress were not correlated with task difficulty for the high priority tasks that did not require search of the display.

There is no indication that attempts on S's part to speed up performance under time stress resulted in loss of accuracy on these high priority tasks, despite the fact that they were chosen to include the simplest and most difficult activities. The generalization is warranted that such high frequency, predictable activities can be expected to be least sensitive to stress in complex tasks, showing little decrement in performance until the time available is no longer adequate for display interpretation and response.

The major effects of stress were found in performance on those tasks involving spatial and temporal uncertainty which required search of the display to identify significant events. For these tasks, location in high and low priority portions of the display and the requirement for short-term memory appear to have been involved in determining performance. Several aspects of these results point to promising directions for further research on the effects of task stress and appear to be of value in the design of operator tasks subject to speed stress.

The first of these concerns the RUN task, which was found to be most susceptible to the effects of stress in that performance showed significant decrement prior to the other tasks. Although the decrement under the intermediate stress condition was greatest for this task at all display locations, it also differed from the other search tasks in that identification

of occurrences on the right was not assisted by location in the high-priority portion of the display. The RUN task differed from the other search activities in several respects. Probability of occurrence was lower for RUN than for PAIR, it required searching and correlating information from more quadrants than LINE, and was the only search task requiring short-term memory. Apparently all of these factors were required in order to demonstrate a difference in performance at the right between a search task and FORM, the simplest activity. However, the range of complexity and frequency of occurrence of the tasks included in this experiment is fairly limited in comparison with most operational situations of interest. We have some indication that in multivariate complex tasks those activities requiring search and memory for identification of low probability events will "break" first under stress.

A second finding of interest is that, with the exception of RUN, differences in performance between the high and low priority display locations were greater than those between search tasks. _Ss_ generally did poorly on all tasks at the left, somewhat better on mixed events, and, with the exception of RUN, best at the right. These differences were larger and more often significant than differences among tasks at the right. At all frame times the probability of _S_ correctly identifying these events was apparently determined to a greater extent by the relative frequency of occurrence of response events at each of the various display locations, than by the frequency or difficulty of events within individual task categories. Whether _S_ searched a particular display location on any given trial, and perhaps the thoroughness of his search, appears to have been determined by the probability of a response event of any

type occurring there, rather than for each task category individually. This is not surprising, since 81 percent of all events, including MEAN and FORM, occurred on the right, 12 percent were mixed events spanning left and right, and 7 percent fell exclusively on the left. The differences between these percentages were greater than those between frequencies of occurrence for the three search tasks, so that there is little reason to expect Ss to have been particularly sensitive to differences in frequency of search task events or to have evolved a search strategy on this basis.

It appears from the data that the information-processing strategies evolved in this task were established primarily on a spatial basis. Search priorities for the various display locations gave rise to differences in performance at all levels of stress, with increased stress acting to limit the portion of the display interval allocated to search of the lower priority display locations. Superimposed on these spatial effects was that found for the RUN task, attributable to neglect of a low probability, complex task appearing in a high priority display location.

These results are similar to some findings in investigations of vigilance behavior. While vigilance studies have typically been concerned with changes in the probability of detection of infrequent signals during the course of a lengthy task, several studies have also demonstrated large differences in failure of attention throughout the course of the task attributable to the probability of occurrence of signals calling for response in different parts of the display, as well as within a background stream of display events.

In one study (Nicely and Miller, 1957) temporal and spatial uncertainty of signals was manipulated by varying signal rates in various parts of the display. With practice Ss learned to bias their attention within the display, detecting a higher proportion of signals in the high probability region than in the low probability area. A study employing event rates approximating the range of frame rates employed in this experiment (Jerison and Pickett, 1964), provides a strong demonstration that Ss are less likely to attend to a display event when few of the events are significant signals requiring response, and more likely to attend and respond correctly when a greater proportion of the events are significant signals. The study of Jerison and Pickett involved monitoring of a single display channel. Another vigilance study (Colquhoun, 1961) employed conditions more similar to those of this experiment, since it entailed scanning a number of display channels. Although differences in signal probability did not influence performance on events in channels at the center of the display, detection of lower probability events was significantly poorer in peripheral display locations.

Jerison and Pickett (1963) have presented an analysis of vigilance behavior in which they distinguish between an observing response phase and a detection response (or psychophysical detection) phase, holding that vigilance phenomena must be attributed to the observing phase. A decision-theory approach to observing behavior is outlined which appears to have great relevance for the analysis of complex information processing under task stress. Selectivity of search for various possible signals is assumed to be determined by a decision matrix based on a priori probabilities, values, and costs, thus adopting the approach successfully applied to the psychophysical study

of signal detection, and earlier proposed as a framework for description of the behavior of the human observer in a variety of perceptual tasks (Swets, Tanner, and Birdsall, 1961).

Application of the statistical decision theory approach to information processing under task stress would assume that _S_ is maximizing the expected utility of observing responses not only in determining whether a display area or information category is attended to, but also in terms of the order in which these activities are carried out and the proportion of available time allotted to each. There are major problems to be faced if decision theory is to be applied fruitfully to such complex situations, calling for some ingenuity in devising experimental tasks which allow for quantative analysis in these terms. The preliminary findings of this study indicate the potential value of research along these lines toward understanding and prediction of the effects of task stress on information-processing performance.

SECTION 5

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